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Searches and Electroweak Measurements at HERA

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The H1 and ZEUS collaborations have used the HERA I data to search for physics beyond the SM and to test electroweak physics in electron-proton collisions. The new period of data taking (HERA II) has started and first HERA II analyses become available. An overview is given of recent highlights, including isolated lepton and multi-lepton events, tests of models of new physics and the first systematic search for deviations in all final states with high transverse momentum.

1 Introduction

The HERA accelerator at DESY in Hamburg collides a 920 GeV proton beam with a 27.5 GeV electron beam. The resulting centre-of-mass energy of 319 GeV and the up to now recorded integrated luminosity of more than $150\,\mathrm{pb}^{-1}$ is large enough to compete with e^+e^- and $p\overline{p}$ colliders in testing many aspects of the Standard Model (SM). The HERA experiments recorded during the HERA I phase (1994-2000) more than $100\,\mathrm{pb}^{-1}$ each. Both the HERA collider and experiments have undergone a major upgrade (HERA II phase) in the years 2000-2001. New final focusing magnets close to the interaction point improve the luminosity and interactions of longitudinally polarised electrons or positrons with protons can now be studied due to the installation of spin rotators. Severe backgrounds prevented the collider experiments from efficient data taking up to the end of 2003. Since then, almost $50\mathrm{pb}^{-1}$ integrated luminosity were recorded by the HERA experiments (till August 2004). Hence this article presents some updates of HERA I results with about 50% more analysed data.

HERA is ideally suited to probe especially electron-quark interactions with virtualities of the exchanged boson in the range of almost 0 up to around $4 \cdot 10^4$ GeV^2. The former is called the photoproduction, the latter the deep-inelastic scattering domain. New physics might be produced in both domains, either via resonant production of new particles or via virtual effects. The HERA data shows sensitivity to various models for new physics. In the following I will discuss how well the data agrees with the SM expectation and present limits on a personal selection of models.

2 Deep inelastic scattering

The measured neutral and charged current cross sections are nicely described by the electroweak SM prediction together with recent parton density functions and the data of the H1 [1] and ZEUS [2] experiments agree well (see Figure 1). This can be interpreted as a test of the electroweak

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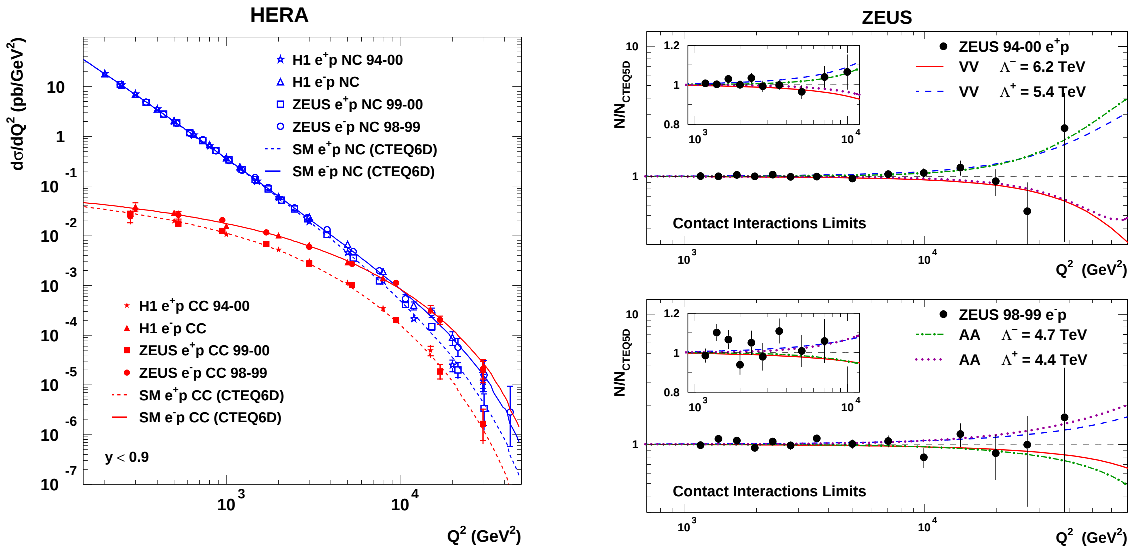

Figure 1: Neutral and charged current cross sections as measured by H1 and ZEUS (left) and a comparison of the ZEUS data to contact interaction models (right).

sector of the SM with $t-$channel W and photon/Z^0 propagators. At a virtuality $Q^2 \approx M_Z^2$ the charged and neutral current cross sections are of almost equal size, showing the unification of weak and electromagnetic forces.

The data show no significant deviation from the expectation and are used to place exclusion limits. The Q^2 spectrum is typically analysed in the framework of so called ‘contact interactions’, where any deviation due to a new particle or current would correspond to a new heavy mass scale [3,4]. The sensitivity of these analyses depends on the chiral structure, i.e. the handedness of the eq-interaction. These general models describe the effects of e.g. heavy leptoquarks or lepton compositeness. Both ZEUS and H1 were able to establish stringent lower limits on the mass scale Λ for positive and negative couplings in the range between 1.6 and 6.2 TeV. The effects of such modifications of the SM are presented in Figure 1 for different scenarios and for positive and negative interference with Standard Model processes. A very similar interpretation of these data leads to lower limits on the mass scale parameters of large extra dimension models as proposed by Arkani-Hamed, Dimopoulos and Dvali of around 0.8 TeV. The limit on the radius of the quark charge is around 0.8×10^{-18} m, calculated using the classical form factor approximation.

3 General search for new phenomena

The H1 collaboration has explored all final state topologies with at least two particles of 20 GeV transverse momentum (P_T) in a “general search” [5]. In this analysis, for the first time, all final state configurations accessible to a collider experiment are investigated. Such an analysis could lead to suprises. Many phase space corners are not looked at if they are not part of a dedicated search driven by a specific model.

In order to ensure a clear separation of final states, all events are classified into exclusive event classes according to the number and types of detected particles (e.g. electron-jet or muon-jet-neutrino). An impressive overall agreement with the predictions is obtained (see figure 2), illustrating the good understanding of Standard Model physics at HERA and of the H1 detector response to the different types of particle.

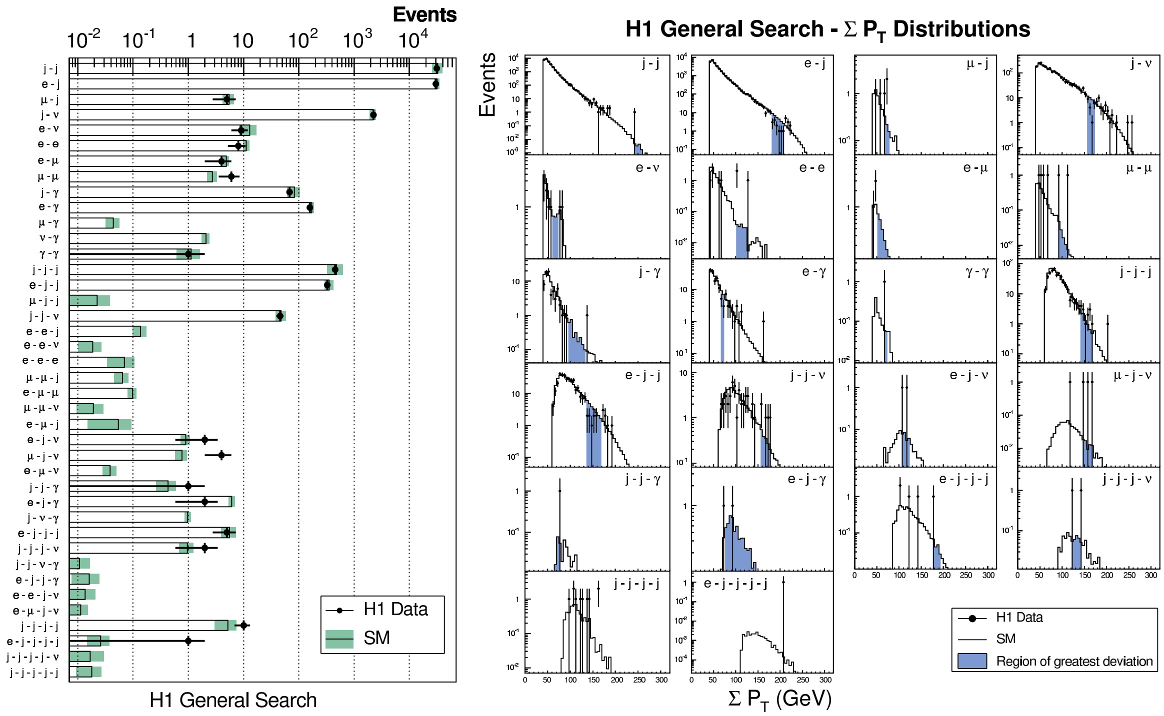

Figure 2: Comparison of the H1 data measured in various final states with the SM prediction (left) and the sum of transverse momenta distributions (right).

In a second analysis step, the distributions of the invariant mass and the scalar sum of transverse momenta of the particles are studied for each class. Since new physics may be visible as an excess or a deficit in some region of one of these distributions, they are systematically investigated using a new search algorithm. The algorithm locates the region with the largest deviation between the data and the SM prediction. Figure 2 shows as an example the sum of P_T distributions of the data and prediction together with the region selected by the algorithm.

To quantify the relevance of the disagreement, the probability $\hat{P}$ of observing a deviation anywhere in the distribution which is at least as significant as that observed is calculated. No highly significant deviations are observed in most of the event classes. The class which shows the largest deviation is that with a muon, a jet and a neutrino. A $\hat{P}$ of below 1% for the invariant mass and about 0.1% for the sum of P_T distribution is calculated. A deviation was also reported previously in this final state in an analysis especially designed to investigate these kind of events and new HERA II results of the analysis are discussed below.

The final output of the "general search" is a list of deviations and their probability $\hat{P}$. In order to get a prediction for these $\hat{P}$ values of the data the whole analyses are repeated many times with pseudo (Monte Carlo) data. The analysis of the "pseudo data" can give answers to questions like: "Given that the SM is correct, in how many H1 experiments do we expect a deviation of similar of larger size than the largest deviation observed in all the data distributions?". The answer is that about 3% (28%) of "pseudo data" sets whould have a larger deviation in the sum of P_T (invariant mass) distributions.

It is highly interesting to see how these values behave for the upcoming HERA II data.

4 Isolated lepton events and single top production

A couple of interesting events have been observed in HERA I data in the analysis of events with a lepton, a jet and missing transverse momentum [6]. More data events than expected were

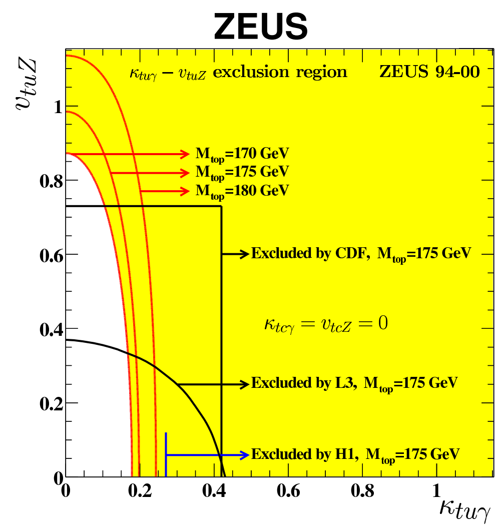

Figure 3: Exclusion regions at 95% confidence level for anomalous top couplings.

seen by the H1 experiment for $P_T^X > 25$ GeV, where P_T^X is the transverse momentum of the hadronic system. The analysis has been updated with recent HERA II data [7]. H1 finds in 163pb^{-1} integrated luminosity 14 events with an electron or muon, while 5.1 ± 1.0 are expected. The SM prediction for these events is dominantly the production of W bosons with high P_T. In the HERA I ZEUS data, in total 7 events are found in the electron and muon channels, while 5.6 ± 0.7 are expected [8]. A clarification of these differences will require a larger data set.

These data have triggered model comparisons, e.g. a flavour-changing neutral-current production of top quarks at HERA and the subsequent leptonic W decay could lead to the event signature of the isolated lepton events. Top quark production via anomalous couplings between the u-quark, a photon and the top ($\kappa_{tu\gamma}$) or between the u-quark, the Z and the top (v_{tuZ}) have been studied by H1 and ZEUS using optimized cuts [9,8]. The H1 analysis finds again the excess in the electron and muon channels and no deviation in the jet channel. The ZEUS analysis finds agreement between data and expectation in all three channels. Stringent limits on anomalous top couplings have been derived as shown in Figure 3.

5 Multi-lepton events

H1 reports furthermore 3 interesting di-electron events with an invariant mass of the di-electron system $M_{ee} > 100$ GeV in 163pb^{-1} HERA I and HERA II data [7]. The SM expectation was found to be 0.44 ± 0.1. In the HERA I data recorded by ZEUS (130pb^{-1}) also 2 events are found with $M_{ee} > 100$ GeV, while 0.77 ± 0.08 are expected [10]. No deviation is found in the di-muon data of both experiments. In the same H1 dataset 3 tri-electron events with an invariant mass of the two highest P_T electrons $M_{12} > 100$ GeV are found. The expectation is 0.31 ± 0.08. In the HERA I data the ZEUS experiment expects 0.37 ± 0.04 and finds no tri-electron event with $M_{12} > 100$ GeV. Again conclusions on these events can only be drawn with a significant amount of additional data.

6 Summary

Recent HERA search highlights are presented, including updates using HERA II data. The HERA I data set has been exploited using searches for deviations in all final state configurations.

Although some interesting events have been observed no evidence for new physics could be established so far. Some tests of specific models are presented as examples and underline that HERA data can still give useful information in testing the SM and probing the physics which might be beyond.

HERA data has also been used to determine exclusion limits [11] on e.g. R_P violating Supersymmetry, Leptoquarks, doubly charged Higgs production, excited fermions and magnetic monopoles and details can be found in recent H1 and ZEUS publications.

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